NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

CONVERSION AND MAINTENANCE OF Co-oP
FOR WINDOWS

by

Mai T. Orloff

December 1993

Principal Advisor: Tung X. Bui

Approved for public release; distribution is unlimited

Unclassified
Security Classification of this page

REPORT DOCUMENTATION PAGE

1a Report Security Classification: Unclassified		1b Restrictive Markings	
2a Security Classification Authority		3 Distribution/Availability of Report Approved for public release; distribution is unlimited.	
2b Declassification/Downgrading Schedule			
4 Performing Organization Report Number(s)		5 Monitoring Organization Report Number(s)	
6a Name of Performing Organization Naval Postgraduate School	6b Office Symbol *(if applicable)* 37	7a Name of Monitoring Organization Naval Postgraduate School	
6c Address *(city, state, and ZIP code)* Monterey CA 93943-5002		7b Address *(city, state, and ZIP code)* Monterey CA 93943-5002	
8a Name of Funding/Sponsoring Organization	6b Office Symbol *(if applicable)*	9 Procurement Instrument Identification Number	
Address *(city, state, and ZIP code)*		10 Source of Funding Numbers Program Element No / Project No / Task No / Work Unit Accession No	
11 Title *(include security classification)* CONVERSION AND MAINTENANCE OF Co-oP FOR WINDOWS			
12 Personal Author(s) Mai T. Orloff			
13a Type of Report Master's Thesis	13b Time Covered From To	14 Date of Report *(year, month, day)* 1993, December	15 Page Count 52
16 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
17 Cosati Codes Field / Group / Subgroup	18 Subject Terms *(continue on reverse if necessary and identify by block number)* Group Decision Support System (GDSS), Graphical User Interface (GUI), multiple criteria decision methods (MCDM), Analytic Hierarchy Process (AHP), ELECTRE, aggregation decision making techniques, consensus seeking algorithm (NAI).		

19 Abstract *(continue on reverse if necessary and identify by block number)*

The purpose of this thesis is fourfold: (1) conduct a review of Co-oP to include its background and the multiple criteria decision making algorithms and group aggregation techniques implemented in the existing version of Co-oP; (2) expand the model base to include ELECTRE 3; (3) expand the group decision module to include the Minimum-Variance technique and a revised version of the Min-Max technique; and (4) migrate CO-OP, using Visual Basic 2.0, onto a graphical user interface (GUI) environment that can be run with Microsoft Windows for Workgroup.

20 Distribution/Availability of Abstract _ unclassified/unlimited _ same as report _ DTIC users	21 Abstract Security Classification Unclassified	
22a Name of Responsible Individual Professor Bui X. Tung	22b Telephone *(include Area Code)* (408) 656-2630	22c Office Symbol AS/Bd

DD FORM 1473,84 MAR 83 APR edition may be used until exhausted
All other editions are obsolete

security classification of this page
Unclassified

Approved for public release; distribution is unlimited

CONVERSION AND MAINTENANCE OF Co-oP FOR WINDOWS

by

Mai T. Orloff
Lieutenant, Medical Service Corps, United States Navy
B.S., California State University Dominguez Hills, 1987

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN INFORMATION TECHNOLOGY MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 1993

Author: Mai T. Orloff
____
Mai T. Orloff

Approved By: Tung Bui
____
Tung X. Bui, Principal Advisor

Kishore Sengupta
____
Kishore Sengupta~~, Associate~~ Advisor

____
David R. Whipple, Chairman
Department of Administrative Sciences

ABSTRACT

The purpose of this thesis is fourfold: (1) conduct a review of Co-oP to include its background and the multiple criteria decision making algorithms and group aggregation techniques implemented in the existing version of Co-oP; (2) expand the model base to include ELECTRE 3; (3) expand the group decision module to include the Minimum-Variance technique and a revised version of the Min-Max technique; and (4) migrate CO-OP, using Visual Basic 2.0, onto a graphical user interface (GUI) environment that can be run with Microsoft Windows for Workgroup.

TABLE OF CONTENTS

I. INTRODUCTION

A. OBJECTIVES

Recently, groupware and computer-supported cooperative work (CSCW) have gained increasing interest among academicians and, especially, practitioners. With the advent of graphical user interface (GUI)-based network operating systems, computer-supported group decision making has become attractive to corporate users. Major software manufacturers such as Microsoft, Lotus, IBM and Borland have recognized groupware as part of their strategic product. Advances in distributed computer systems development and design, in effect, have paved the way for automated group decision making, negotiation and collaborative group work.

This thesis is part of a project undertaken to upgrade Co-oP - a group decision support system (GDSS) for cooperative multiple criteria group decision support systems (MCGDSS) developed by Dr. Tung X. Bui. Co-oP is a network of microcomputer-based, process-driven DSS. Each participant has his own individual DSS whose model base is based on multiple criteria decision methods (MCDM) and other personal decision support tools. The group DSS contains a set of aggregation of preferences techniques and consensus seeking algorithms that is used in conjunction with individual MCDM. (Price, 1991)

The purpose of this thesis is fourfold:

- conduct a review of Co-oP to include its background and the multiple criteria decision making algorithms and group aggregation techniques implemented in the existing version of Co-oP,

- expand the model base to include ELECTRE 3,

- expand the group decision module to include the Minimum-Variance technique and a revised version of the Min-Max technique and

- migrate Co-oP, using Visual Basic 2.0, onto a GUI environment that can be run with Microsoft Windows for Workgroup.

The programming codes for the implementation of the system are not included in this thesis due to the size of the application.

B. SCOPE

This thesis proposes a set of MCDM algorithms that has proven its effectiveness in support of decision making and that fits current Co-oP architecture (Bui, 1987). It will focus on developing the system and conducting extensive 'alpha' testing. Limited 'beta' testing will be accomplished using 'textbook' examples with graduate students at Naval Postgraduate School.

C. ORGANIZATION OF THE THESIS

This thesis is divided into three subsequent chapters. Chapter II briefly discusses the background of Co-oP and the GUI design principles adopted for the system. Chapter III presents Co-oP system processes, using GUI design, and briefly describes the individual and group DSS algorithms, respectively. It is not within the scope of this thesis to provide an indepth analysis of each algorithm. Chapter IV provides both conclusions and recommendations for further research. And, finally, the Appendix provides some samples of input and output screens of the system.

D. PROGRAM DISCLAIMER

In its current state, the software described herein is neither ready nor intended for use as the sole basis for decision making, where the outcome may affect health, safety, national defense or any other issue of significance.

II. FRAMEWORK FOR Co-oP/W (WINDOWS VERSION)

This chapter briefly summarizes the underlying concepts leading to the design and implementation of Co-oP. These concepts are extensively discussed in the literature. Readers who wish to gain understanding of these concepts in greater depth are invited to consult the literature (see, for example, Turban 1993).

A. BASIC CONCEPTS OF DECISION SUPPORT SYSTEMS

Decision Support Systems (DSS) are applications designed specifically to assist decision makers in the process of problem evaluation and resolution. Composed of a database, a database management system (DBMS), a model base (one or more models) and a user interface, a DSS is equipped to support a broad array of judgements and managerial competencies. Powerful modeling and analytical capabilities permit the exploration of problems of both an unstructured and semi-structured nature. (Price, 1991)

To be effective, the process of evaluating alternatives must employ a means by which several decision criteria can be considered at the same time.

> Multiple Criteria Decision Making (MCDM) methods allow for the analyses of several criteria simultaneously. These criteria may be either quantifiable (cost, weight, etc.) or non-quantifiable (quality of service, aesthetics, etc.). Because these criteria affect one another, the improvement of one criteria often affects the quality of another. MCDM also allows the decision maker to make a

subjective evaluation, which can be expressed by weighing the evaluation criteria, making pairwise judgements or simply giving an ordinal ranking of a set or subset of alternatives. MCDM is intended to aid the decision maker to assess objectives that may affect the decision making process and to improve the coherence between the decision making process and the changes in the user's preferences. (Price, 1991, pp. 6-7)

These methods support personal judgement at the individual decision maker level. Today's competitive marketplace demands a decision support process capable of capitalizing on the broad-breadth and diverse expertise of many. A multiple criteria group approach to decision support, which recognizes individual preference and (where necessary) seeks consensus, is specifically designed to achieve that goal.

B. HISTORY OF Co-oP

Co-oP was published for the first time in 1984 (Bui and Jarke, 1984). The version of the software was written in Pascal with ELECTRE I as the only MCDM methods for individual evaluation and the Min-Max technique as the algorithm for computing group results. The Negotiable Alternative Identifier (NAI) was developed in 1985 (Bui, 1985) to offer some analytical information to the group members when consensus can not yet be reached. An early experimental study was conducted to test the usefulness of Co-oP (Bui et al., 1987). Using Naval officers as decision makers, the controlled experiment suggested that, given a multiple criteria decision problem, using Co-oP tends to enhance not only the quality of the decision outcomes but also the quality

of the decision making process. The entire Co-oP project was documented in 1987 (Bui, 1987) and the system was subjected to another laboratory experiment, this time with the focus on distributed decision making (Bui and Sivasankaran, 1990). The migration of Co-oP to the windows environment commenced in 1992. This thesis provides additional MCDM and aggregation techniques to the system.

C. GRAPHICAL USER INTERFACE DESIGN PRINCIPLES

According to Microsoft (1992a), the evolution and proliferation of contemporary applications creates an ever-expanding body of interface issues and opportunities. As a result, a set of general principles exist which are intended to both guide and optimize the software design and implementation process.

1. User Control

The user should be in control of the application. To facilitate this, an application must be as interactive as possible, using non-interactive modes only where absolutely necessary and only where accompanied by a visual indicator. For example, when a computing process requires a waiting period, the pointer shape changes to an hourglass shape to indicate that the user will have to wait until the process is complete before further interaction can occur.

An application must also enable users to open and/or re-size several windows simultaneously for the purpose of visual comparison. This increases user confidence in the application.

Lastly, an application must facilitate the task at hand in as transparent a fashion as is possible. Application demands should be minimized so as not to become obstacles to accomplishment, themselves.

2. Directness

To be effective, the interface should provide users with both direct and intuitive methods to accomplish tasks - the object-action paradigm. Direct manipulation (i.e., object selection and then action selection) is user friendly as opposed to complex command entry.

3. Consistency

Applications should capitalize on the user's real-world experience, using familiar concepts and relationships in an effort to minimize the amount of new material a user must learn. In addition, applications should employ standard interface elements to benefit a cross-section of potential users, as well as, follow-on design and development.

4. Clarity

Visual elements should be real-world related with comprehensible functions. Conceptual metaphors should be simple and realistic. And, interface text should be clear and unambiguous.

5. Aesthetics

Interface appeal and visual clarity and, therefore, its utility are enhanced by employment of basic graphic design principles. These include an integrated consideration of space, contrast and three-dimensional representation.

6. Feedback

Immediate and tangible feedback for actions within an application is an essential element of interface design. Graphical feedback may be enhanced by both textual and auditory options.

7. Accommodation

To facilitate self-motivated learning, an interface must accommodate user exploration and the potential for error (both physical and mental), without penalty. In design, the opportunity for error should be minimized and, once detected, errors should be resolved in an objective and blameless manner.

8. Recognition of Human Capacity

Applications typically focus on the broad-breadth linguistic and visual capabilities of users. However, to be effective, an interface must recognize and adapt to user limitations in perception, memory and reasoning. Applications should internally address and compensate for these limitations rather than force the user to overcome them.

9. Color

According to Microsoft (1992b), the proper use of available color contributes to the user friendly objectives of applications interface. The target market for Windows 3.x (the environment for Visual Basic) is VGA resolution computers. There are sixteen system colors in VGA:

Table I: VGA SYSTEM COLORS

Yellow	Magenta	Cyan	Gray
Dark Yellow	Dark Magenta	Dark Cyan	Dark Gray
Red	Blue	Green	White
Dark Red	Dark Blue	Dark Green	Black

Although the human eye is capable of distinguishing between a substantial array of colors, an interface must minimize potential color confusion in order to capitalize on color perception. For the purposes of this analysis, color vision can be conceptualized using a few basic principles:

a. Trichromacy

Each color in the visible spectrum can be reduced mathematically to groups of three numbers. The human retina perceives color as red, green or blue.

b. Classification

Colors are classified in terms of three properties: hue, saturation and brightness. Hue is the name of the color, saturation its intensity and brightness is its location on a scale of dark to light.

c. Opponent Colors

Color has spatial properties - edges of objects are seen as black or white and edged-in areas appear filled in with color. Color is seen in relationship to other colors in the surrounding area. If opponent colors (e.g., red and green) are used together, they appear to vibrate when viewed.

d. Psychological Properties of Color

Color possesses emotional properties which can stimulate learning when used correctly. Proper selection of color can improve application 'friendliness' and, as a result, product marketability.

e. Employing Color

Since color attracts the eye, it should be used to direct attention. Although the human mind tends to group like colors together on a screen, it is slow to associate a color with a meaning (e.g., red means edit mode, etc). Since bright colors tend to leave opponent 'after-images' on the retina, large areas of bright colors should be avoided. Due to the human potential for color confusion, color should be used as a redundant cue coupled with other forms of guidance to indicate a property or function. Most importantly, subtle colors are the least distracting and, therefore, the most useful in terms of enhancing the user interface experience.

III. SYSTEM PROCESSES AND DECISION TECHNIQUES

A. SYSTEM PROCESSES

The Co-oP system is process-driven. Figure 3.1 is Co-oP's main screen. The system consists of five basic steps:

(1) group problem and norm definition,

(2) individual prioritization of evaluation criteria,

(3) individual selection method and evaluation of alternatives,

(4) direct input of individual evaluation

(5) group result computation using techniques of aggregation of preferences.

Looking at the process flow (Figure 3.1), the user can readily understand that step (4) can be used in place of steps (2) and (3). This substitution is subject to the user's discretion.

The first step permits the group to define or modify decision elements such as alternatives and evaluation criteria. It also allows the group to input its members' information and assign group and individual passwords. In addition, the group has the opportunity to determine which information exchange mode (Figure 3.2) and group decision techniques (Figure 3.3) will be employed.

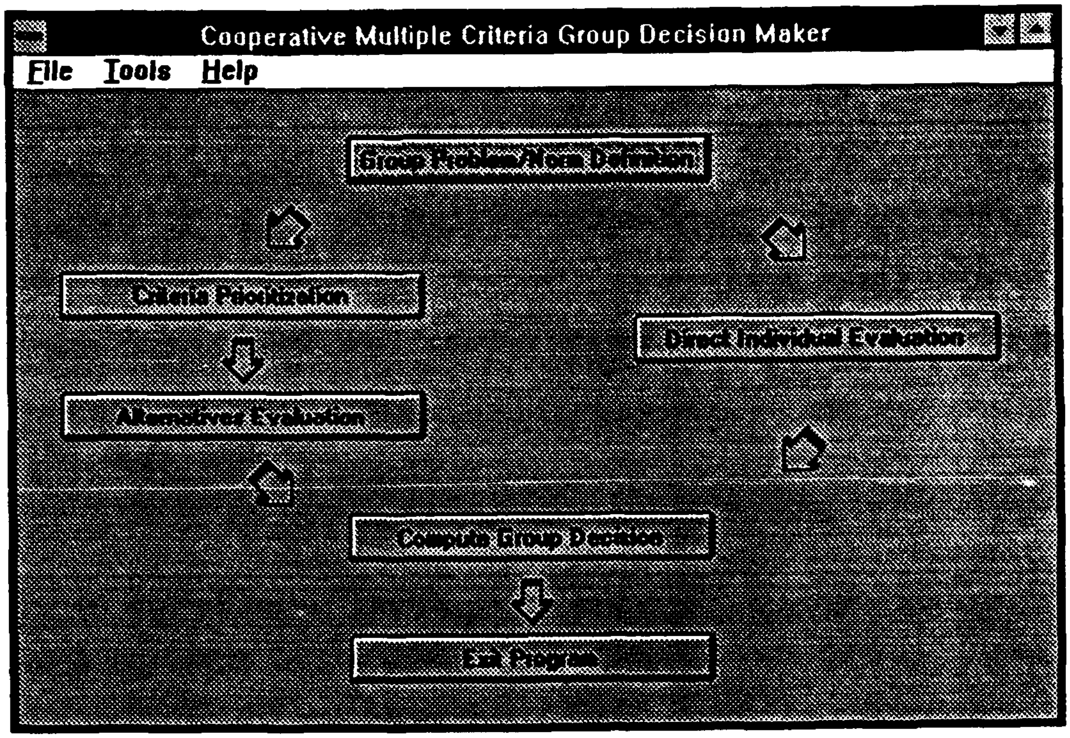

Figure 3.1. Co-oP Main Screen

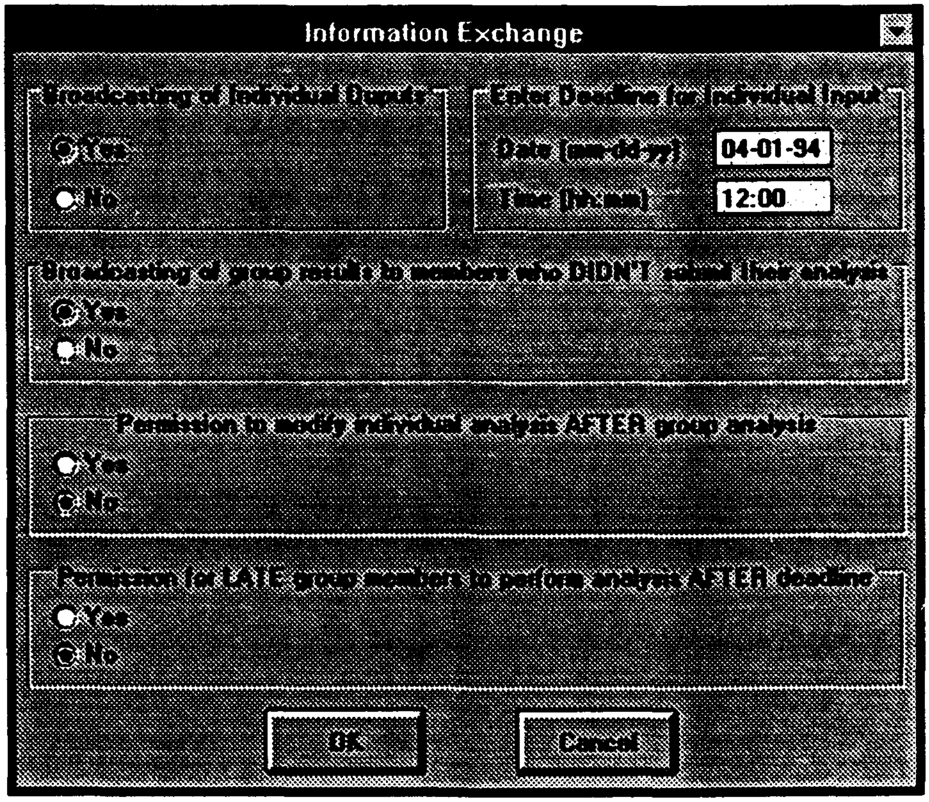

Figure 3.2. Information Exchange Mode Screen

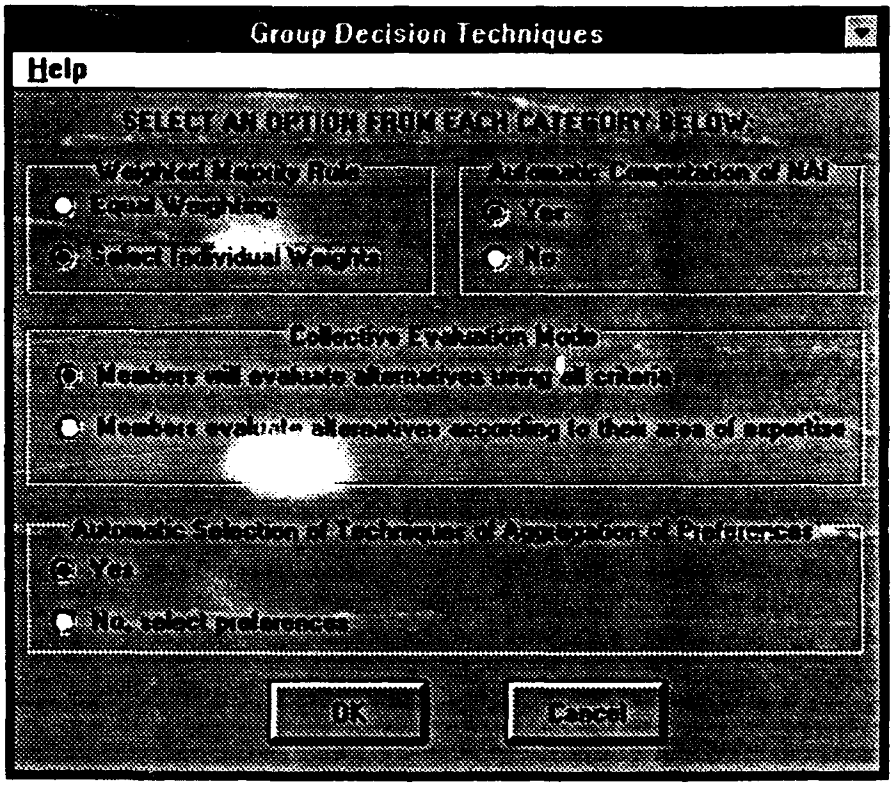

Figure 3.3. Group ision Techniques Selection Screen

Step (2) allows group members to select an evaluation method and evaluate criteria. The evaluation method can be either direct input or Analytic Hierarchy Process (AHP). These two methods are also used in evaluating the alternatives and will be further discussed in section B. The criteria prioritization process is performed in a collective evaluation mode determined in step (1). Each group member can evaluate all criteria or each can evaluate a subset of criteria according to their expertise.

Steps (3) and (4) allow decision makers to individually select a preferred method of multiple criteria decision making (MCDM) to evaluate alternatives. Five methods of MCDM in Co-oP will be discussed in section B.

The final step computes group results using aggregation of preferences techniques. Six techniques of aggregation of preferences have been implemented. If no dominating alternative can be reached, the negotiable alternative identifier (NAI) technique will be evoked to seek consensus. These techniques will be discussed in section C.

B. MULTIPLE CRITERIA DECISION METHODS (MCDM) FOR INDIVIDUAL DECISION MAKERS

Five methods for solving multi-criteria decision problems have been implemented in Co-oP/W (Windows version). Their basic concepts are as follows:

1. Direct Input Without Criteria Evaluation

This is the simplest method of alternative evaluation. It is used only when the decision maker doesn't need support from the system to perform his/her analyses. In this method, prior criteria evaluation is not necessary because the decision maker already has a clear-cut opinion as to what alternatives should be chosen or ranked. Using this method, the decision maker enters the weight of each alternative directly. A vector of cardinal ranking is computed by normalizing the weights. An ordinal ranking vector is also computed where the best alternative is ranked number 1. The two vectors will be used in appropriate aggregation methods to calculate the group results.

2. Direct Input With Criteria Evaluation

This method is an extension of the direct method discussed above. In this and all subsequently mentioned MCDM methods for individual decision makers, the criteria must be weighed separately prior to evaluating the alternative. Using this method, the decision maker can directly enter the weight of each alternative according to each criterion.

3. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process is used to support complex decision problems. AHP's main foundation is the concept of priority which can be defined as 'level of strengths' of one alternative relative to another. This method assists the decision maker to build a positive

reciprocal matrix of pairwise comparison of alternatives for each criterion. A vector of priority is computed from the eigenvector of each matrix. The sum of all vectors of priorities forms a matrix of alternative evaluation. The final vector of priorities is calculated by multiplying the criteria weighted vector by the matrix of alternative evaluation. The best alternative has the highest priority value. Cardinal ranking vectors and ordinal ranking vectors are generated for the computation of the group methods.

4. ELECTRE 1

ELECTRE 1 (**EL**imination **E**t Choix **T**raduisant la **RE**alite) is used when the decision maker doesn't want to compare some alternatives because of uncertainty associated with the measurements and evaluation, or due to incomparability between them; e.g., alternative A is better than alternative B by some criteria, whereas B is better than A by some other criteria. ELECTRE 1 is based on the concept of outranking relations. A outranks B if it can be safely justified that A is at least as good as B. In order to compare one alternative to the other, concordance and discordance indices are computed, respectively, using the following formulas:

$$C_{A/B} = \frac{\text{Sum of the weights of the criteria by which A's evaluation >= B's evaluation}}{\text{Total weights of all criteria}}$$

$$D_{A/B} = \frac{\text{The greatest negative variation (i.e., B > A) between the evaluations for a single criterion}}{\text{The difference between highest grade and lowest grade of the criterion}}$$

The concordance index $C_{A/B}$ indicates to what extent alternative A is better than alternative B. The perfect alternative has $C_{A/B} = 1$.

The discordance index $D_{A/B}$ indicates to what extent alternative A contains discordant elements that makes A unsatisfactory compared to B. A totally unacceptable alternative has $D_{A/B} = 1$.

A concordance threshold P and a discordance threshold Q are chosen between [0, 1] to determine the outranking relation index $O_{A/B}$ as follows:

$$O_{A/B} = \begin{cases} 1 & \text{(A outranks B) if } C_{A/B} >= P \text{ and } D_{A/B} <= Q \\ 0 & \text{otherwise} \end{cases}$$

As the concordance threshold P approaches 1 and/or the discordance threshold Q approaches 0, it becomes more difficult for an alternative to outrank another. The outranking vector of each decision maker will be used in the Min-Max aggregation technique discussed in section C below.

5. ELECTRE 3

As an extension of ELECTRE 1, ELECTRE 3 shares the concept of outranking relation. However this concept is applied differently to render a ranking order of decision alternatives. The following are symbols and formulas used in this method:

A/B = alternative A outranks alternative B

IT = indifference threshold

PT = strict preference threshold

VT = veto threshold

j = criterion considered

The credibility index for each criterion is:

$$d_{j(A/B)} = \frac{PT_j - \min((B_j - A_j), PT_j)}{PT_j - \min((B_j - A_j), IT_j)}$$

The concordance index (for all criteria) is:

$$C_{(A/B)} = \sum_{j=1}^{n} w_j * d_{j(A/B)}$$

where w_j = weight of criterion j

The discordance index is:

$$D_{j(A/B)} = \min[1, \max(0, \frac{(B_j - A_j), PT_j)}{VT_j - PT_j})], where VT_j \geq PT_j$$

The global credibility index is:

$$d_{(A/B)} = C_{(A/B)} \prod \frac{(1 - D_{j(A/B)})}{1 - C_{(A/B)}}$$

if $D_{j(A/B)} > C_{(A/B)}$

A discrimination threshold DT in the interval [0, 1] (DT is more severe when it approaches 0) is introduced to calculate the ascending and descending distillations which are used to produced an ordinal ranking and cardinal ranking for group results. For a complete discussion of the ELECTRE 3 algorithm, see Bui and Pasquier-Dorthe (1986).

C. GROUP DECISION MAKING TECHNIQUES

Co-oP uses six techniques of aggregation from Bui (1987). As a product of this thesis effort, the Minimum-Variance method and the Min-Max method have been implemented with the Co-oP/W version 1.0 in addition to four existing techniques: Sums-of-the-Ranks, Additive Ranking, Multiplicative Ranking and Sums-of-the-Outranking-Relations. In conjunction with the techniques of aggregation of preferences, the weighted majority rule is also implemented (when applicable) to account for the distribution of decision power among decision makers. This rule allows the group members to differentiate their decisional power according to various degrees of expertise or organizational hierarchies.

These techniques use the following definitions:

n = number of alternatives

u = number of decision makers

a_i = alternatives a_i (for $i = 1,..,n$)

$Card_{a_i d}$ = cardinal ranking of alternative a_i (for $i = 1,...,n$) by decision maker d (for $d = 1,...,u$), where for each d

$$\sum Card_{a_i} = 1$$

$Ord_{a_i d}$ = ordinal ranking of alternative a_i (for $i = 1,...,n$) by decision maker d (for $d = 1,...,u$)

$O_{a_i a_k d}$ = outranking relation
(= 1) indicating that a_i outranks a_k (for $i, k = 1,...,n$) by decision maker d (for $d = 1,...,u$)
(= 0) indicating that there is no outranking relation

Wgt_d = decision weight of each decision maker d (for d = 1,...,u), where (Wgt_d>=1)

1. Sums-of-the-Ranks Rule

This technique suggests the result as the minimum of the sum of the ordinal ranking for each alternative made by all group members.

$$Min[\sum_{d=1}^{u} Ord_{a_i d} | i=1,...,n]$$

For weighted rule, the ranking value is multiplied by the weight of each decision maker.

$$Min[\sum_{d=1}^{u} (Ord_{a_i d} * Wgt_d) | i=1,...,n]$$

The following example demonstrates the non-weighted method:

Alternative	DM1	DM2	DM3	Sums-of-the Ranks
a_1	4	3	1	8
a_2	3	1	2	6 <- Min
a_3	2	2	3	7
a_4	1	4	4	9

The weighted values of the above example are as follows:

Alternative	DM1 $Wgt_1=4$	DM2 $Wgt_2=1$	DM3 $Wgt_3=2$	Sums-of-the Ranks
a_1	4	3	1	21
a_2	3	1	2	17
a_3	2	2	3	16 <- Min
a_4	1	4	4	16 <- Min

Alternative a_2 is the result of the non-weighted method, while both alternatives a_3 and a_4 are the result of weighted method. Due to its computational simplicity, this technique is widely used to determine consensus ranking.

2. The Additive Ranking

The Additive Ranking method in Co-oP is slightly different from the one described in Bui (1987). It is normalized by the total of all cardinal values of the group instead of being the arithmetic mean of the rankings. The selected alternative is defined as:

$$Max\left[\frac{\sum_{d=1}^{u} Card_{a_i d}}{Total} \middle| i=1,\ldots,n\right]$$

where

$$Total=\sum_{i=1}^{n}\sum_{d=1}^{u} Card_{a_i d}$$

For weighted value, it is defined as:

$$Max\left[\frac{\sum_{d=1}^{u}(Card_{a_i d} * Wgt_d)}{Total}\middle| i=1,\ldots,n\right]$$

where $$Total=\sum_{i=1}^{n}\sum_{d=1}^{u}(Card_{a_i d} * Wgt_d)$$

Below is an example of non-weighted values:

Alternative	**DM1**	**DM2**	**DM3**	**DM4**	**Additive Ranking**
a_1	.4	.3	.3	.1	.275
a_2	.2	.2	.2	.6	.30 <- Max
a_3	.1	.4	.0	.1	.15
a_4	.3	.1	.5	.2	.275

The weighted values of the above example appear below:

Alternative	**DM1** $Wgt_1=3$	**DM2** $Wgt_2=1$	**DM3** $Wgt_3=4$	**DM4** $Wgt_3=2$	**Additive Ranking**
a_1	.4	.3	.3	.1	.29
a_2	.2	.2	.2	.6	.28
a_3	.1	.4	.0	.1	.09
a_4	.3	.1	.5	.2	.34 <- Max

3. The Multiplicative Ranking

A group evaluation of each alternative is the product of the cardinal ranking made by all group members raised to the power of u decision makers. The selected alternative has the highest group ranking. The multiplicative effect allows an individual to impose his/her veto.

For non-weighted method, the resultant value is:

$$Max[\sqrt[u]{\prod_{d=1}^{u} Card_{a_i d}} | i=1,...,n]$$

For weighted method, the resultant value is:

$$Max[\sqrt[u]{\prod_{d=1}^{u} (Card_{a_i d} * Wgt_d)} | i=1,...,n]$$

Below is an example of non-weighted values:

Alternative	DM1	DM2	DM3	DM4	Multipl. Ranking
a_1	.4	.3	.3	.1	.24
a_2	.2	.2	.2	.6	.26 <- Max
a_3	.1	.4	.0	.1	.0
a_4	.3	.1	.5	.2	.23

4. The Sums-of-the-Outranking-Relations Principle

This technique is defined as follows:

$$Max[\sum_{d=1}^{u} O_{a_i a_k d} | i=1,...,n; k=1,...,n; a_i \neq a_k]$$

The weighted rule is not applicable in this method due to the nature of outranking relations.

> This technique should be used only with extreme care. Experience with this technique has shown that the idea of selecting the alternative that has the highest number of outranking relations works fine only when the number of alternatives are small. (Bui, 1987, p. 56)

The following is an example of this method:

Ordinal Ranking				**Outranking Relations**				
Rank	**DM1**	**DM2**	**DM3**	**Alt**	**a_1**	**a_2**	**a_3**	**Sums of the Relations**
1	a_1	a_3	a_3	a_1	-	2	1	3
2	a_2	a_1	a_2	a_2	1	-	1	2
3	a_3	a_2	a_1	a_3	2	2	-	4 <- Max

(Bui, 1987, p. 57).

5. The Minimum-Variance Method

This method is an extension of the sums-of-the-ranks method. It brings the group rankings closer to the true rankings of the alternatives. It suggests the results as:

$$Min[\sum_{d=1}^{u} (Ord_{a_i d}-Ave_{a_i})^2 | i=1,...,n]$$

where
$$Ave_{a_i}=\frac{1}{n}\sum_{d=1}^{u} Ord_{a_i d}$$

For weighted rule, the result is:

$$Min[\sum_{d=1}^{u} (Ord_{a_i d}*Wgt_d-Ave_{a_i})^2 | i=1,...,n]$$

where $$Ave_{a_i} = \frac{1}{n}\sum_{d=1}^{u} Ord_{a_i d} * Wgt_d$$

The following is an example for non-weighted rule for both the sums-of-the ranks and Minimum-Variance methods:

Alter.	**DM1**	**DM2**	**DM3**	**Sums of the Ranks**	**Minimum Variance**
a_1	4	3	1	8	6
a_2	3	1	2	6 <- Min	2.75
a_3	2	2	3	7	1.69 <- Min
a_4	1	4	4	9	7.69

6. The Min-Max Principle

This method is the safest and unquestioned principle in dealing with group problem solving. It works only when individual opinions are not extreme and/or the number of alternatives is large enough to generate consensus (Bui, 1987). It is used only with ELECTRE 1 results. The group concordance index, C^G, the group discordance index, D^G, the group concordance threshold, P^G, and the group discordance threshold, Q^G, are respectively computed as follows:

$$C^{G}_{a_i a_k} = \min[C_{a_i a_k d} | d=1,...,u]$$

$$D^{G}_{a_i a_k} = \max[D_{a_i a_k d} | d=1,...,u]$$

where alternative a_i outranks a_k

$$P^{G} = \max[P_d | d=1,...,u]$$

$$Q^{G} = \min[Q_d | d=1,...,u]$$

The following example (with typographical correction added) is from Bui and Jarke (1984) where STQ, M30 and M50 represent three different alternatives.

DECISION MAKER 1

Concordance Matrix

	STQ	M30	M50
STQ	-	28	28
M30	72	-	95
M50	72	15	-

Discordance Matrix

	STQ	M30	M50
STQ	-	80	60
M30	35	-	15
M50	80	45	-

Outranking Matrix for P=.7, Q=.35

	STQ	M30	M50
STQ	-	0	0
M30	1	-	1
M50	0	0	-

DECISION MAKER 2

Concordance Matrix

	STQ	M30	M50
STQ	-	45	45
M30	80	-	90
M50	65	75	-

Discordance Matrix

	STQ	M30	M50
STQ	-	75	75
M30	25	-	25
M50	50	25	-

Outranking Matrix for P=.75, Q=.25

	STQ	M30	M50
STQ	-	0	0
M30	1	-	1
M50	0	1	-

GROUP

Concordance Matrix

	STQ	M30	M50
STQ	-	28	28
M30	72	-	90
M50	65	15	-

Discordance Matrix

	STQ	M30	M50
STQ	-	80	75
M30	35	-	25
M50	80	45	-

Outranking Matrix for P=.75, Q=.25

	STQ	M30	M50
STQ	-	0	0
M30	0	-	1
M50	0	0	-

7. The Negotiable Alternative Identifier (NAI) Method

According to Bui (1987), this method is used when no consensus is reached by using the six aggregation techniques previously mentioned. Negotiation becomes necessary to analyze and resolve individual differences. This method is composed of three operations: expansion, contraction and intersection, all of which are based on the following observations.

> First, in order to improve the chance of reaching consensus, the decision makers should exhibit some flexibility regarding their individual assessment of preferences. Second, they should be able to identify exchangeable or negotiable alternatives. (Bui, 1987, p. 62)

The expansion operation differentiates individual ranked alternatives into two sets of preferences: the preferred and the least preferred. Within each set, the alternatives have negligible differences in cardinal ranking. This would expand the confidence of the decision makers from one best alternative to a set of almost equally preferred alternatives.

Given the preferred set from the expansion operation, the contraction operation attempts to identify if there are any alternatives that exhibit a stronger preferential distribution than others. If there exists such an indicator, the set will be regrouped into the most preferred set and the preferred set.

The third and last step of the NAI algorithm is the intersection operation. It selects the common solutions from all decision makers's most preferred set and preferred set. When the collective most preferred is empty, the decision makers may be satisfied with the solution(s) from the group preferred set.

For interested readers, a detailed discussion of the NAI algorithm can be found in Bui (1985), Kardos and Kutz (1986).

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

With the expansion of the model base to include ELECTRE 3, the expansion of the group decision module to include the Minimum-Variance technique and the Min-Max technique, and the conversion of the system to a GUI environment, the new Co-oP - Co-oP/W (Windows version) - becomes a more powerful analytical tool and easier to use.

B. RECOMMENDATIONS FOR FUTURE WORK

The system is currently implemented in Microsoft Visual Basic 2.0 which doesn't provide database management features. Visual Basic 3.0, with a complete database management system (DBMS), is recommended for upgrading Co-oP/W 1.0. With a DBMS, Co-oP will run more efficiently in terms of reducing response time, and minimizing both memory consumption and data storage requirements.

To facilitate a group of multilingual decision makers, multilingual options should be added in Co-oP.

The current Co-oP is limited to a finite set of solutions. PROMETHEE IV should be implemented to solve this problem, given its capacity for an infinite set of solutions.

APPENDIX

Co-oP SYSTEM SCREEN SAMPLES

The purpose of this appendix is to familiarize the reader with Co-oP/Windows. Providing a complete walk-through example for the Co-oP/W 1.0 exceeds the scope of this thesis. The interested reader is advised to seek a copy of the software to gain a full appreciation of Co-oP functionalities. This appendix presents window screens that relate to the techniques described in Chapter III.

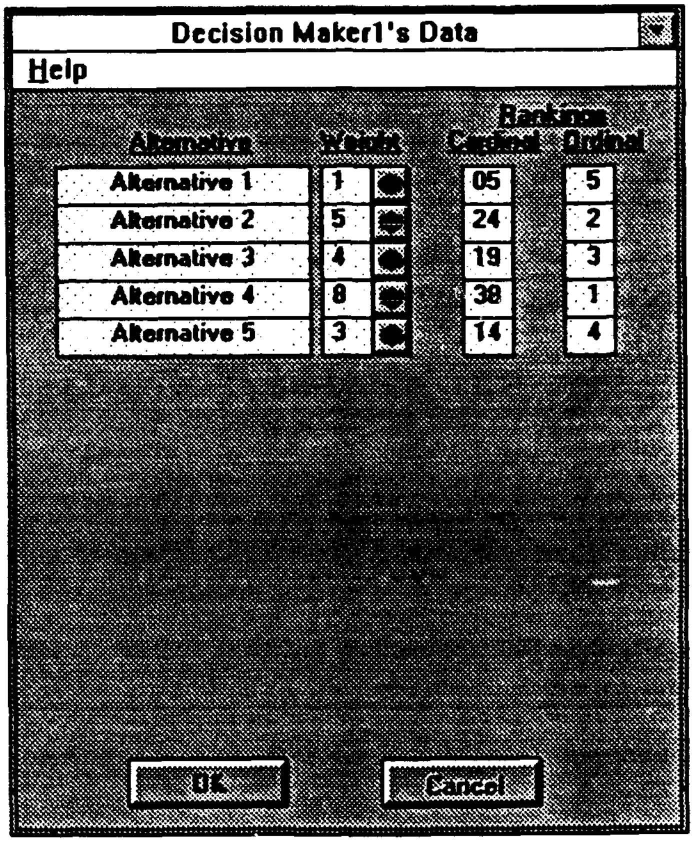

Figure A.1. Direct Input Without Criteria Evaluation Screen

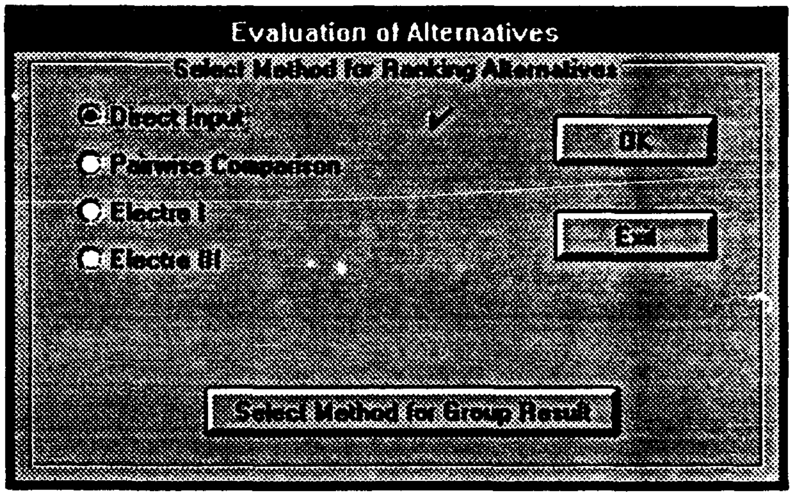

Figure A.2. Alternative Evaluation Menu

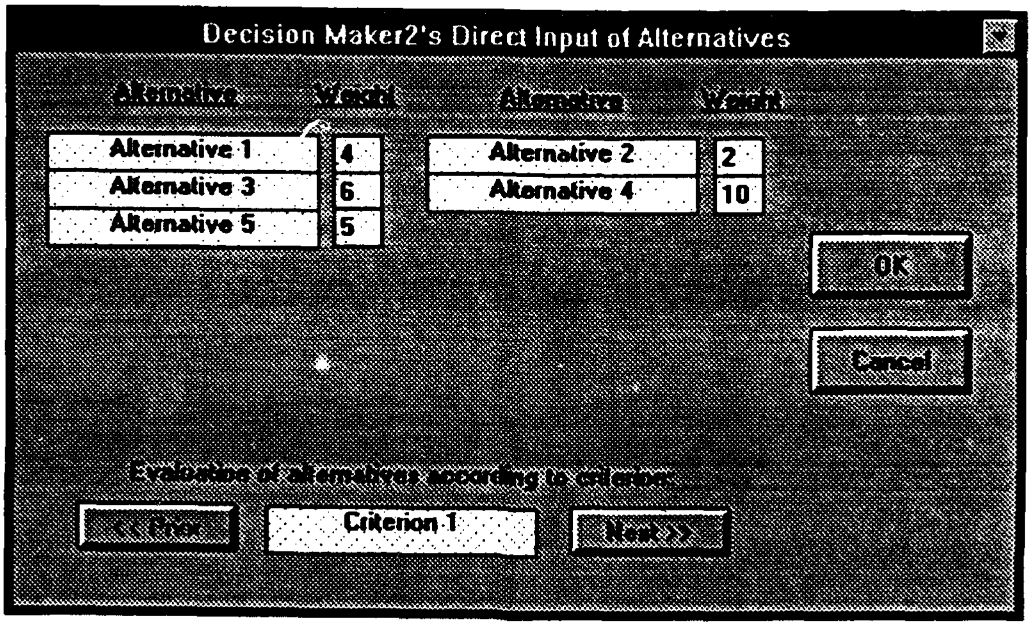

Figure A.3. Direct Input Screen

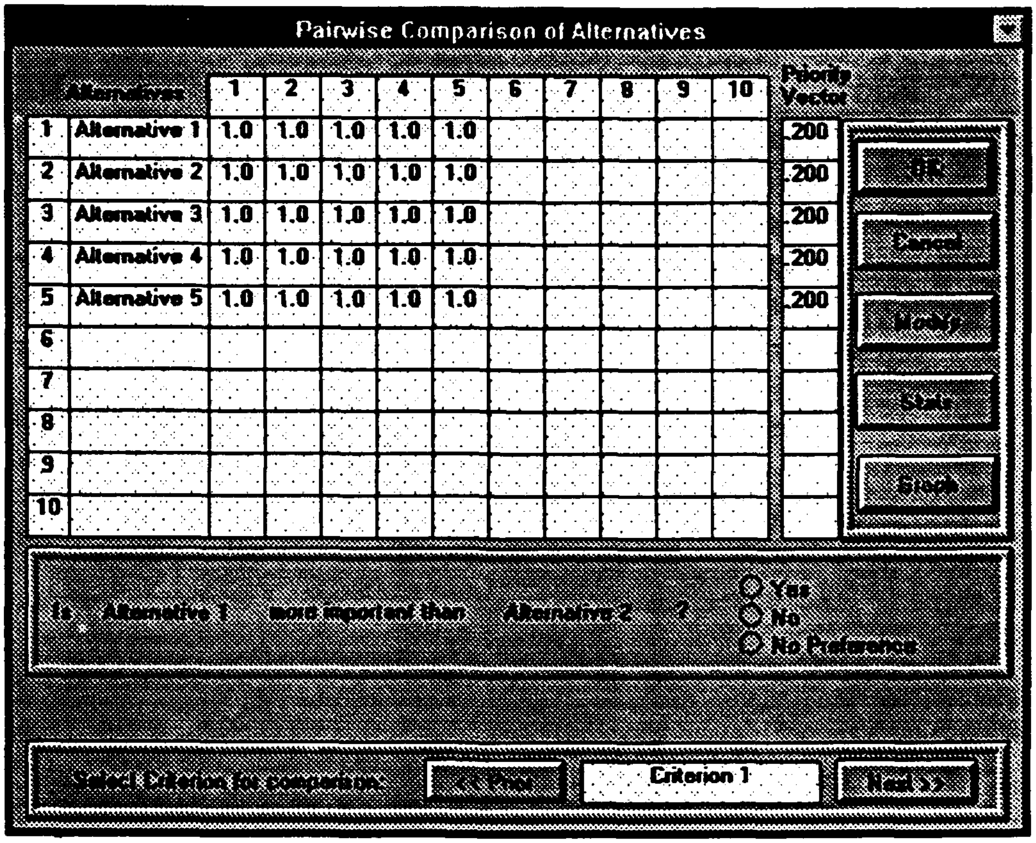

Figure A.4. AHP (Pairwise Comparison) Input Screen

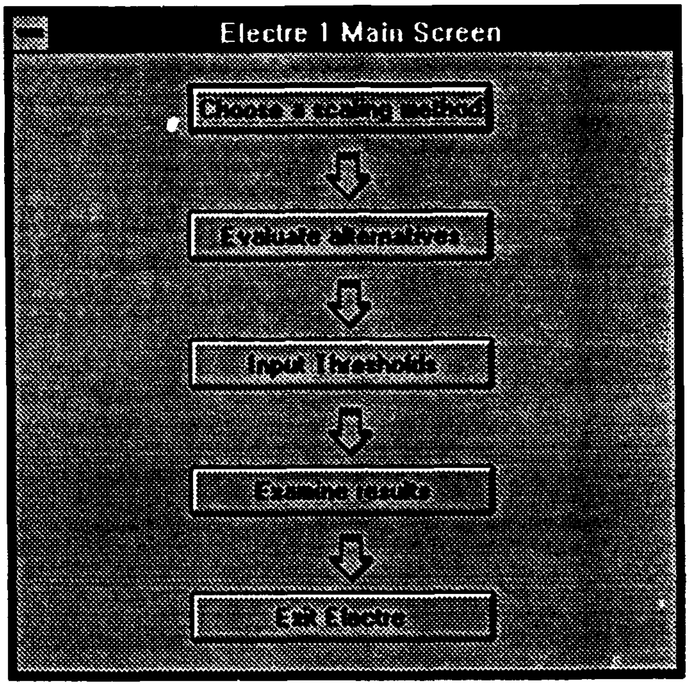

Figure A.5. ELECTRE Main Screen

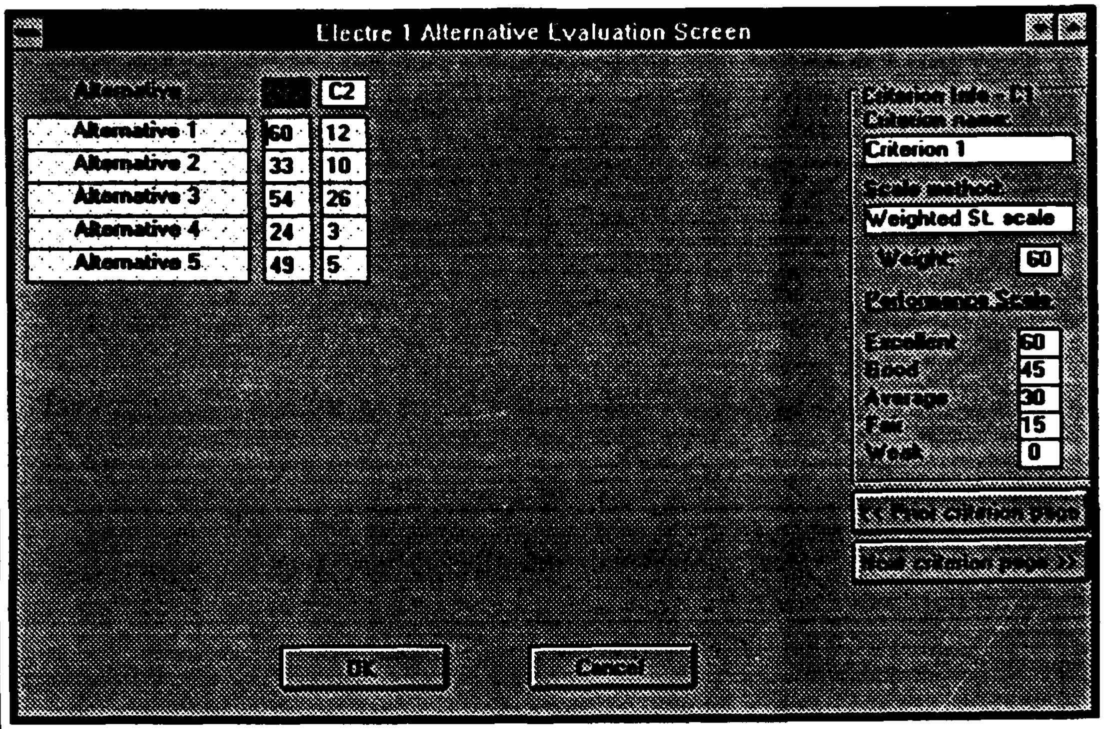

Figure A.6. ELECTRE Input Screen

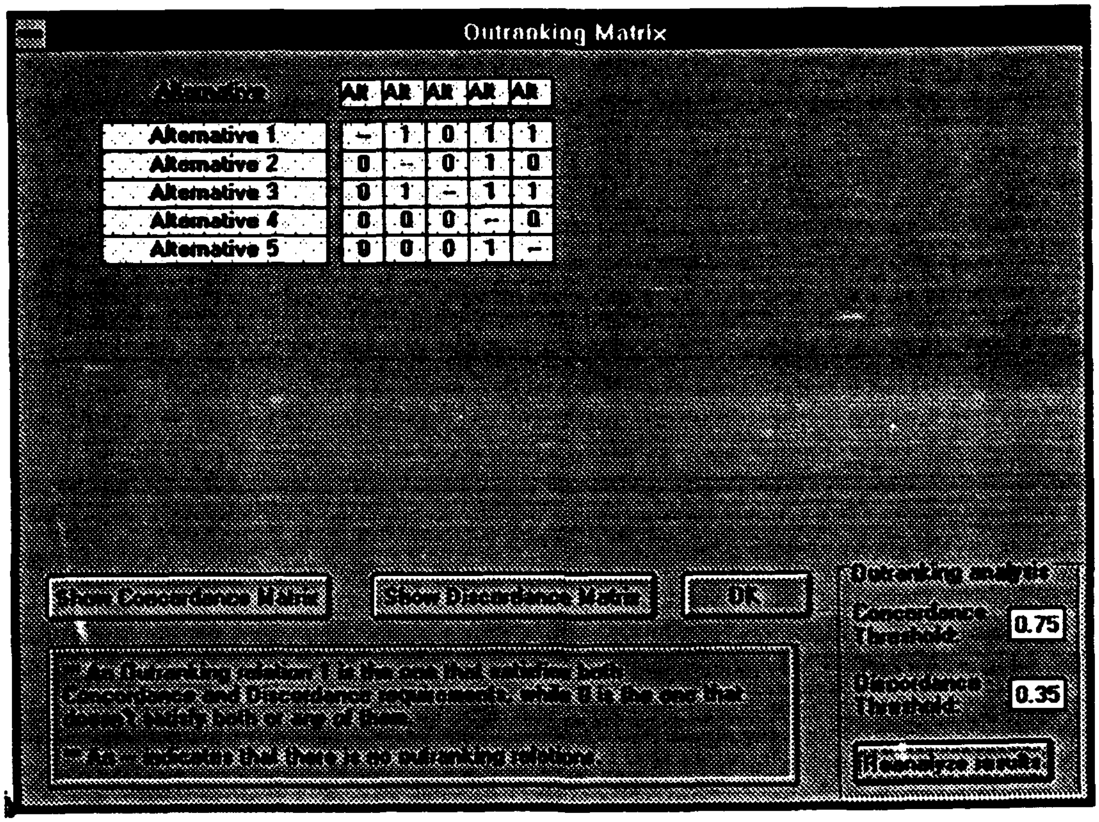

Figure A.7. Outranking Matrix for ELECTRE 1 or Min-Max Rule

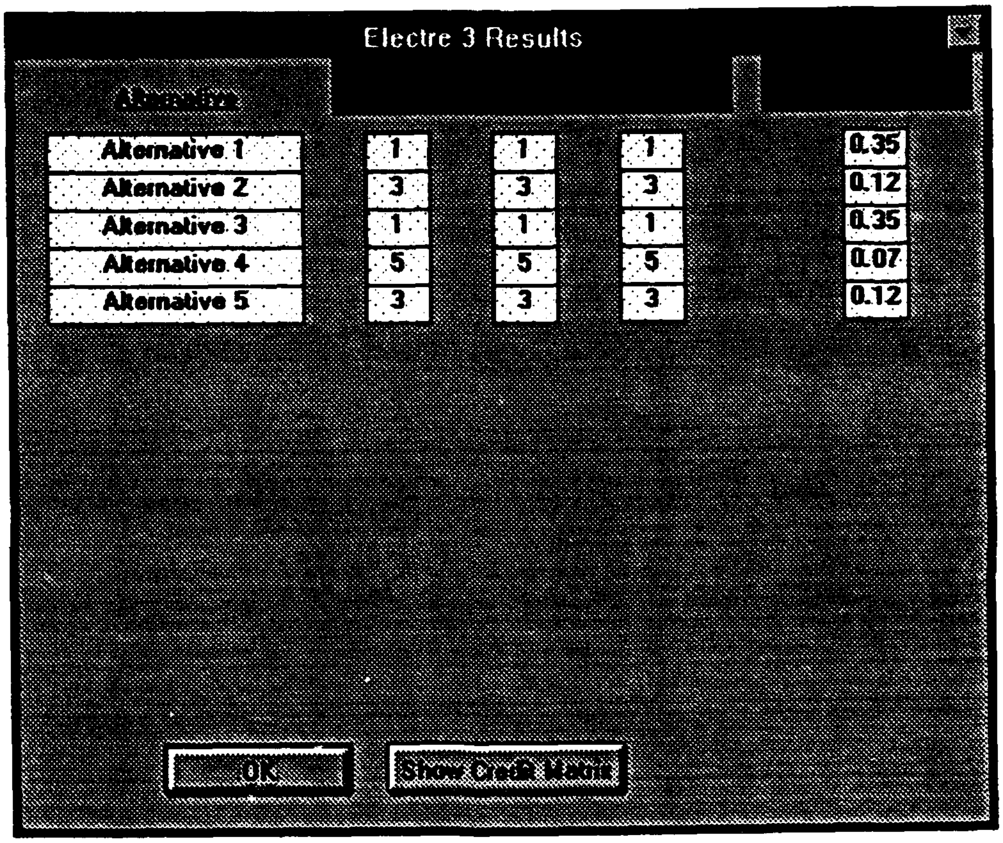

Figure A.8. ELECTRE 3 Results Screen

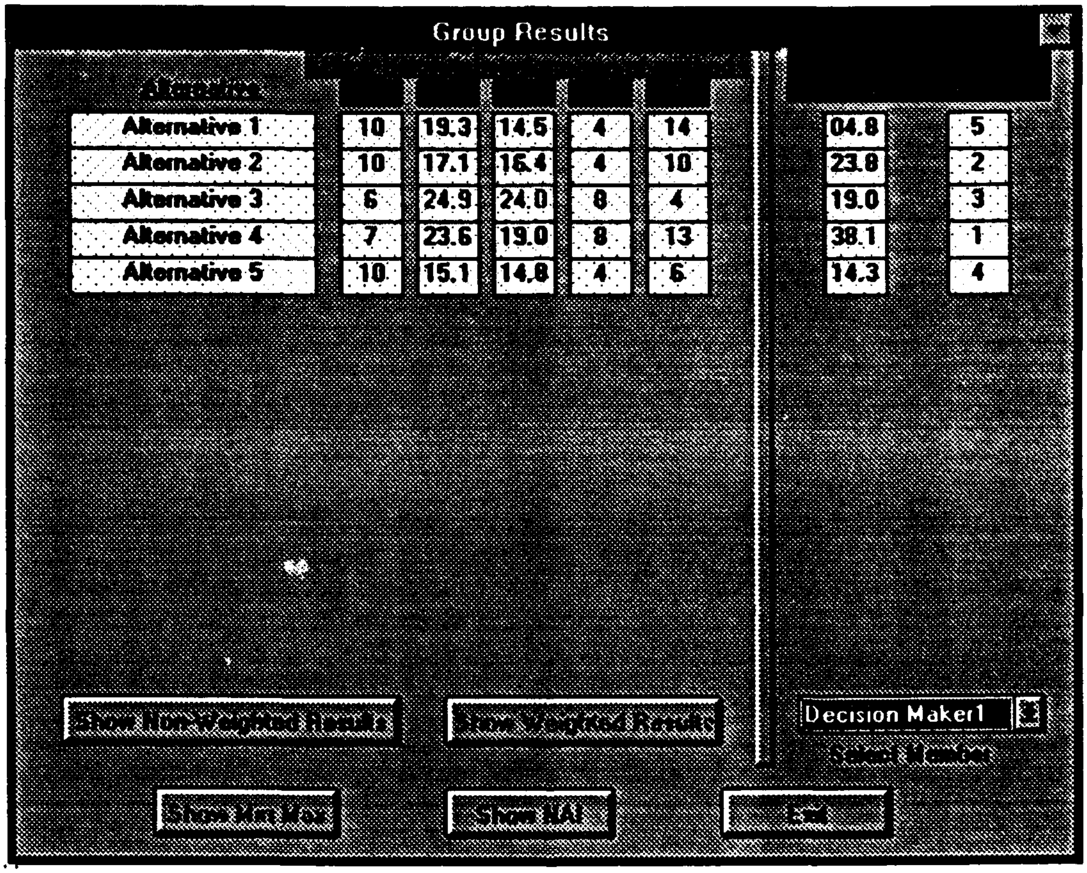

Figure A.9. Group Results Screen

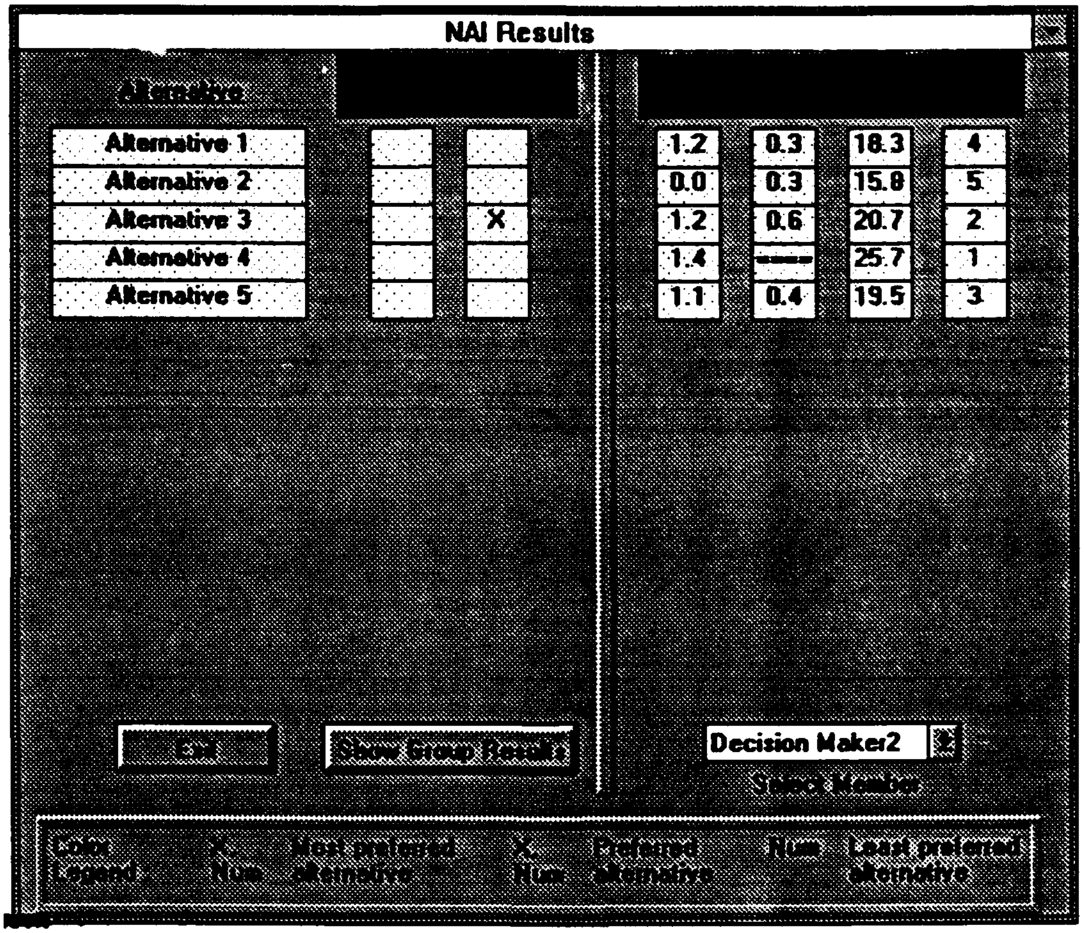

Figure A.10. NAI Results Screen

LIST OF REFERENCES

Bui, T. X., NAI -- A Consensus Seeking Algorithm for Group Decision Support Systems, Proceedings of the 1985 International Conference on Systems, Man and Cybernetics, Tucson, Arizona, November 1985.

Bui, T. X., Co-oP, a Group Decision Support System for Cooperative Multiple Criteria Group Decision Making, Springer-Velag, 1987.

Bui, T. X. and M. Jarke, A DSS For Cooperative Multiple Criteria Group Decision Making, Proceedings of the Fifth International Conference on Information Systems, Tucson, Arizona, 1984.

Bui, T. X. and J. Pasquier-Dorthe, La Methode ELECTRE 3 DE Bernard Roy, Universite de Fribourg, Suisse, Seminaire d'economie d'entreprise et de gestion financiere, 1986.

Bui, T. X. and T. Sivasankaran, Integrating Modular Design with Adaptive Design in DSS Prototyping: An Archepelagian Approach, Proceedings of the 20th Annual Hawaii International conference of System Sciences, 1987.

Bui, T. X., T. Sivasankaran, Y. Fiyol and M. Woodberry Identifying Organizational Opportunities for GDSS Use: Some Experimental Evidence, DSS-87 Transactions, San Francisco, 1987.

Bui, T. X. and T. Sivasankaran, Relation Between GDSS Use and Group Task Complexity: An Experimental Study, IEEE, 1990.

Kardos, A. and E. Kutz, Non-cooperative Group Decision Support System: Problems and Some Solutions, Master Thesis, Naval Postgraduate School, Monterey, California, September 1986.

Microsoft, The Windows Interface: An Application Design Guide, Microsoft Windows Software Development Kit, 1992.

Microsoft, Visual Design Guide, Microsoft Visual Basic 2.0, 1992.

Price, C. T.,Jr., Multiple Criteria Decision Models For the Co-oP Group Decision Support System, Master Thesis, Naval Postgraduate School, Monterey, California, March 1991.

Turban, E., Decision Support and Expert Systems, Management Support Systems, MacMillan, 1993.

INITIAL DISTRIBUTION LIST

1.	Defense Technical Information Center Cameron Station Alexandria, VA 22304-6145	2
2.	Library, Code 052 Naval Postgraduate School Monterey, CA 93943-5002	2
3.	Commanding Officer Naval Health Sciences Education and Training Command, Code 2MSC Bethesda, MD 20814-5022	1
4.	Professor Bui X. Tung, Code AS/Bd Department of Administrative Sciences Naval Postgraduate School Monterey, CA 93943-5103	2
5.	Professor Kishore Sengupta, Code AS/Se Department of Administrative Sciences Naval Postgraduate School Monterey, CA 93943-5103	1
6.	Lt. Mai T. Orloff 1220 7th ST #1 Monterey, CA 93940	7